Diagnostic accuracy of ultrasonography for hand bony fractures in paediatric patients

Elena Neri,1 Egidio Barbi,1 Ingrid Rabach,1 Chiara Zanchi,1 Stefania Norbedo,1 Luca Ronfani,1 Veronica Guastalla,2 Alessandro Ventura,3 Pierpaolo Guastalla1

ABSTRACT

Objective Hand fractures are common in childhood, and radiography is the standard diagnostic procedure. US has been used to evaluate bone injuries, mainly in adults for long-bone trauma; there are only a few studies about hand fractures in children. The purpose of this study was to evaluate and confirm the safety and applicability of the US diagnostic procedure in comparison to X-ray diagnosis.

Study design This cross-sectional study involved a convenience sample of young patients (between 2 and 17 years old) who were taken to the emergency department due to hand trauma. After clinical assessment, patients with a suspected hand fracture first underwent X-ray, and subsequently US examination by two different operators; a radiologist experienced in US and a trained emergency physician in “double-blind” fashion. US and radiographic findings were then compared, and sensitivity as well as specificity was calculated.

Results A total of 204 patients were enrolled in the study. Seventy-nine fractures of phalanges or metacarpals were detected by standard radiography. When US imaging was performed by an expert radiologist, 72 fractures were detected with sensitivity and a specificity of 91.1% and 97.6%, respectively. Sensitivity and specificity were found to be (respectively) 91.5% and 96.8% when US was performed by the ED physicians.

Conclusions US imaging showed excellent sensitivity and specificity results in the diagnosis of hand fractures in children. The study also showed a great agreement between the results of the US carried out by the senior radiologist and those carried out by the paediatric emergency physician, suggesting that US can be performed by an ED physician, allowing a rapid and accurate evaluation in ED and could become the first diagnostic approach whenever a hand fracture is suspected.

Injuries and minor trauma comprise approximately one-third of all visits to emergency departments (ED) in children.1 Radiography is routinely performed for the evaluation of bone injuries, but the possibility of using a non-invasive technique without exposure to ionising radiation has raised the interest in the use of US for fracture diagnosis.2 This method is rapid and cost-effective, and it has no adverse effects.3

The use of US is recommended for fracture evaluation because of its high-resolution evaluation of the cortex that appears as a bright, hyperechoic line with posterior shadowing, with the epiphyseal cartilage and plate appearing anechoic to hypoechoic with the hyperechoic epiphyseal core in the centre.4 Discontinuities in the bone’s contour in the site of trauma correspond to cortical disruption, evidence of a fracture (figures 1 and 2). Using high-frequency transducers, it is possible to recognise cortical interruptions up to 1 mm of size.5 US can also be used to capture dynamic images of soft tissues structures. One of the main advantages of US is assessing the possible site of pain: bone pain induced by fractures is rarely reported at a site far from the fracture responsible for it due to this fact, focused diagnostic investigations can reduce the need to obtain numerous radiograms of whole skeletal segments as potential fracture sites.6 Several studies have shown that ED physicians with adequate training can rapidly diagnose fractures in children using US.5 7 Recent studies have shown the efficiency of US to detect diaphyseal fractures, even though sensitivity and specificity decrease when evaluating the bone near joints because of the curved and often irregular contours at the ends of bones.1 4 and the presence of epiphyseal plates.1 3 For this reason,
several studies that have reported high sensitivities for US in the
detection of fractures have excluded end-of-bone and near-joint
fractures. There are few studies on the applicability of US for
the diagnosis of hand fractures in adults\(^8\) and still less in
children.\(^9\)

The primary aim of our study was to evaluate the diagnostic
accuracy of US performed by an expert radiologist in compari-
son to X-ray for the identification of bony hand fractures (meta-
carpals and phalanges).

Secondary intentions were to evaluate the accuracy of US per-
formed by specifically trained paediatric emergency physicians
compared with X-ray and the correlation between US performed
by the radiologist and the paediatric emergency physicians.

METHODS

Study design

This cross-sectional study was carried out at the ED of a
third-level hospital in Italy (Institute for Maternal and Child
Health—IRCCS “Burlo Garofolo”, Trieste). The ED admits an
average number of 22 000 children per year; the average X-ray
number for suspect hand and finger fracture is 100 per month.
The study was approved by the local Ethical Committee. The
study population consisted of consecutive patients enrolled pro-
spectively who met predetermined inclusion criteria for which
informed consent for study participation was obtained from the
parents.

Selection of participants

Criteria for participation included a maximum age of 17 years
and physical examination findings of possible fractures of the
hand (metacarpals or phalanges), such as swelling, localised
pain, movement, impairment and deformity.

Exclusion criteria included open wounds directly over the
area of injury that prevented US evaluation, dislocation, fracture
in the same area in the preceding 6 months, injuries caused by
road accidents or suspected child abuse.

Study procedure

After clinical assessment in the ED, patients with suspected frac-
tures were referred to the Radiology Department for X-rays that
were evaluated by a senior radiologist. US was performed by a
second radiologist, experienced in US who was blinded to the
X-ray result, and at a later time, by a trained emergency physi-
cian blinded to the result of both X-ray and US performed by
the radiologist.

To further guarantee blindness to the results, X-ray results
were not given to patients or their parents until the end of the
data collecting.

In a first phase of the study, 51 patients were evaluated with
US only by the radiologist in order to assess a prelimin-
ary feasibility of this approach.

Following the US examination, each investigator recorded
separately on a data collection form whether or not a fracture
was identified and the location of the suspected fracture,
The prevalence of fracture in the study population was at 35%.

To adequately evaluate the primary study outcome, it was estimated that the enrolment of 200 subjects was needed, setting the level of the lowest sensitivity to 85% for the comparison of fractures compared with X-ray results. The number of radiographs performed on 204 patients was 530 in total, with an average of 2.6 radiographs per patient. The results for the radiologist US interpretation compared with radiography results are shown in Table 1 (sensitivity 91.1%, specificity 97.6%, positive predictive value 96.0% and negative predictive value 94.6%).

Of the 204 enrolled subjects, 153 were also evaluated by a trained emergency physician. In this group, the X-ray confirmed the presence of fracture in 59 patients (38.6%). The results on the comparison between US carried out by the ED physicians and X-ray are shown in Table 1 (sensitivity 91.5%, specificity 96.8%, positive predictive value 94.7% and negative predictive value 94.8%).

The agreement between the results of the US carried out by the senior radiologist and those carried out by the emergency paediatrician was excellent (K=0.9, p<0.001).

Clinical findings such as oedema, haematoma and functional limitation were collected, but no correlation was found between clinical findings and X-ray and US findings.

### DISCUSSION

This study shows the accuracy of US in diagnosing hand fractures in children in the ED both when performed by an expert radiologist and by a trained emergency paediatrician.

The accuracy of US in detecting long-bone fractures is considered quite good in the literature, while more difficulties have been reported in the evaluation of short bones and bones near

### RESULTS

From November 2012 to May 2013, 204 patients were admitted for hand trauma. No patients were excluded due to open wounds. Study enrolment was proposed to the 204 eligible patients, and all of them were accepted. All enrolled patients could be scanned and completed the study. Patients were younger than 18, age range 2–17, with a mean age of 12 years (SD=3 years), 133 (65%) were male.

In 79 of the 204 enrolled subjects (38.7%), the presence of fracture was confirmed by standard radiography. The number of radiographs performed on 204 patients was 530 in total, with an average of 2.6 radiographs per patient. The results for the radiologist US interpretation compared with radiography results are shown in Table 1 (sensitivity 91.1%, specificity 97.6%, positive predictive value 96.0% and negative predictive value 94.6%).

<table>
<thead>
<tr>
<th>Author, publication year</th>
<th>Location of fracture</th>
<th>Number of patients</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barata, 2012</td>
<td>Long bones</td>
<td>53 (&lt;18 years)</td>
<td>95.3</td>
<td>85.5</td>
</tr>
<tr>
<td>Weinberg, 2010</td>
<td>All districts</td>
<td>212 (&lt;25 years)</td>
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<td>92</td>
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<tr>
<td>Eckert, 2012</td>
<td>Forearm</td>
<td>76 (1–14 years)</td>
<td>96.1</td>
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<td>All districts</td>
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<td>93</td>
</tr>
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<td>Humerus, femur</td>
<td>58 (&gt;18 years)</td>
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<td>83.3</td>
</tr>
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<td>Rabiner, 2013</td>
<td>Elbow</td>
<td>130 (3 m–21 years)</td>
<td>98</td>
<td>70</td>
</tr>
<tr>
<td>Hubner, 2000</td>
<td>All districts</td>
<td>163 (&lt;18 years)</td>
<td>98.3</td>
<td>69.3</td>
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### Table 2 Published studies on sonographic evaluation of bone fractures (Joshi modified12)

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<th>Number of patients</th>
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without knowledge of the X-ray results. The clinical characteristic of the suspected fractures (presence of oedema, haematoma, functional limitation) was also recorded.

### Outcome measures

The outcome of the study was the diagnostic performance of the US performed by the radiologist in comparison to the results of the reference gold standard (X-ray) evaluated by a senior radiologist, and the evaluation of the diagnostic performance of the US carried out by the emergency paediatricians in comparison to the results of the X-rays as reference gold standard: the correlation between the results of US carried out by the radiologist and those carried out by the emergency paediatrician.

### Statistical analysis

Sensitivity, specificity and positive and negative predictive values of US in the identification of fractures compared with X-ray were calculated. Data are reported as percentages with a 95% CI. To evaluate the agreement between the results of US carried out by the radiologist and by the emergency paediatrician, Cohen’s K was calculated. To adequately evaluate the primary study outcome, it was estimated that the enrolment of 200 subjects was needed, setting the level of the lowest sensitivity acceptable at 90%, the CI around this level at 5% and the prevalence of fracture in the study population at 35%.

### Table 1 Diagnostic accuracy of US performed by an expert radiologist (gold standard) and by the ED physician in comparison to X-ray (gold standard)

<table>
<thead>
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<th>Outcome measures</th>
<th>US performed by radiologist</th>
<th>US performed by ED physician</th>
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<tbody>
<tr>
<td></td>
<td>Percentage (absolute numbers)</td>
<td>95% CI</td>
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<tr>
<td>Sensitivity</td>
<td>91.1% (72/79)</td>
<td>84.8 to 97.4%</td>
</tr>
<tr>
<td>Specificity</td>
<td>97.6% (122/125)</td>
<td>94.9 to 100.0%</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>96.0% (72/75)</td>
<td>88.7 to 98.7%</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>94.6% (122/129)</td>
<td>89.6 to 97.3%</td>
</tr>
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ED, emergency department.
joints because of the curved and often irregular contours and for the presence of epiphyseal plates, which may be misdiagnosed as fractures.\(^1\)\(^\text{6}\) For this reason, in most of the studies these parts have been excluded from case series.

Table 2 shows the rates of sensitivity and specificity in the available studies.\(^11\)\^-\(^14\)

In our study, sensitivity and specificity are remarkably similar to those of previous studies even if our investigation involved only hand bones, which are small bones with fractures often involving bone near joints.

In the first phase of the study, 51 patients were evaluated with US only by radiologist to assess the actual feasibility of ultrasonography in the diagnosis of fracture. Initially most challenging, as also reported in literature, was the evaluation of the bones near joints. We have seen, however, that comparing the traumatized bone segment with the adjacent one or with the contralateral finger decreased the possibility of error significantly.

Interestingly in this study, US examination provided a limited number of false positive and false negative results. In particular, given the high specificity (97.6% for radiologists and 96.8% for ED physicians) and the consequently very low number of false positives, a positive result effectively confirms the presence of the fracture. The false negatives were around 9% both for radiologists and for ED physicians, in line with the results of previous studies (table 2).

In most cases, the errors of the ED physician and radiologist were on the same patient and always for the evaluation of bones near joints, misinterpreting growth plates as fractures or in one case sesamoid bone as a fracture with detachment.

The US was routinely performed only on the injured area, as reported by the patients, as well as on the area of swelling, and compared with the other hand. No patient needed an US of the whole hand. In this series, only nine patients were under the age of 4 and all of them collaborated. Even though age and patient’s cooperation must be considered as a limitation of this approach.

In our setting, considering a prevalence of fractures around 38–39%, these results lead to positive and negative predictive values around 95%, meaning that the presence of a positive or negative result of the US supports the fact that the patient have or does not have the fracture.

In our experience, the US examination was brief (about 3 min) and was safe and harmless without considerable strain or stress for the children. The use of the water bath technique allows for the maximum visualisation of the underlying tissues with the water being somewhat of a relief for the pain and an interface that avoids the direct contact between the probe and the injured hand. The routine comparison of the traumatized finger with the adjacent or contralateral one may reduce the possibility of error. Furthermore, the study shows a good performance of the US carried out by the ED physician, who underwent a short training. The diagnostic accuracy was similar to that of radiologists, and the agreement between the results of the US carried out by the senior radiologists and those carried out by the emergency paediatricians was excellent.

This study has some limitations: high quality of US machine and probes at high frequencies are needed, US is a highly operator-dependent technique, manual skill and setting of the US play a relevant role, the great majority of patients were older kids while age and cooperation of the patient may limit this approach, the number of patients is still limited so that these results need to be confirmed by further studies. On the other hand, the US could be considered a fifth step of the objective examination of the patients for the ED physician.

In conclusion, this study shows the safety and applicability of the US diagnostic procedure for hand fractures in children with a 90% sensitivity when compared with X-rays. The study also shows a good agreement between the results of the US carried out by the senior radiologist and those carried out by the paediatric emergency physician, suggesting that US can be performed by trained ED physicians, allowing a rapid and accurate evaluation in ED.

Contributors Each author listed in this document has seen it and approved its submission, and takes full responsibility for it. All authors contributed equally to the manuscript’s draft.

Competing Interest None.

Patient consent Obtained.

Ethics approval The study was approved by the local Ethical Committee.

Provenance and peer review Not commissioned; externally peer reviewed.

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